REFERENCE LWT-1

EXAMPLE WIND TURBINE PROTOTYPE DEVELOPMENT PLAN

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SCOPE OF WORK

The scope of work for this Prototype Development Project requires the Subcontractor to select a wind turbine system for development based upon the belief that it will achieve a combination of improved performance, increased reliability and decreased cost such that the COE objective of the project is met. Considerable emphasis is placed on engineering documentation and periodic formal reviews, so that as corollary objectives of the project, international certification is facilitated and market acceptance of the turbine is achieved.

The Subcontractor shall assign a competent Project Manager, preferably with proven wind-energy experience, to act as the primary interface with the National Renewable Energy Laboratory (NREL) and to oversee all aspects of the subcontract. He or she shall comply with the reporting requirements of the subcontract and coordinate the participation of NREL's Project Manager in important project activities. The Subcontractor's Project Manager shall also ensure that Environmental Safety and Health (ES&H) and Quality Assurance (QA) concerns are addressed in planning and performing each work task.

The project shall begin with the development by the Subcontractor of a *Project Work Plan* that describes the details of the subcontract effort and is intended to establish the timing for, and guide the design, fabrication and testing of, the wind turbine prototypes. A *Certification Plan* shall also be developed to obtain design approval and type certification by a recognized international certification agency. The Subcontractor then shall conduct a *Kickoff Meeting* at its facilities within ninety days of the subcontract award date. At this meeting, the Subcontractor shall convene its key team members and the NREL Technical Review Team. In addition to the draft Project Work Plan, the Subcontractor shall discuss all aspects of the subcontract effort that have preceded the Kickoff Meeting.

The Subcontractor is currently performing design trade-off studies. Under the *Conceptual Design* task of the subcontract, these studies shall continue as necessary throughout the project to investigate key issues that may have a significant impact on the project goals and objectives. In connection with this task, the Subcontractor shall select a "baseline" turbine as a point of departure for subsequent work. This baseline turbine may be an existing machine for which field test data are available, or it may be a "point design" consisting of drawings, specifications and engineering calculations resulting from the conceptual design studies.

The Subcontractor shall pursue a process of preliminary design, detailed design (component development), final design (systems integration), fabrication and field-testing applied first to a proof-of-concept (POC) turbine, then to an engineering and manufacturing development (EMD) turbine and finally to the NGT production prototype. Although the Prototype Development Project is not intended to support commercial development of the POC turbine, the POC turbine may be used as an engineering tool in support of the NGT development.

In the *Preliminary Design* subtask, the Subcontractor shall review the proposed design concept, including components and subsystems, to assure that all relevant experience and information have been considered. It shall then integrate the selected components and subsystems into a preliminary design of the proposed turbine. At the conclusion of this subtask, the Subcontractor shall be able to describe in considerable detail the configuration that it proposes to develop to achieve the project goals and objectives.

In the *Detailed Design (Component Development)* subtask, the Subcontractor shall design, fabricate, test and evaluate components and subsystems that are candidates for use on the proposed turbine. The Subcontractor shall demonstrate, either through appropriate laboratory and field tests or through the application of generally-accepted engineering practice, that the selected components and subsystems meet specified design criteria.

In the *Final Design (Systems Integration)* subtask, the Subcontractor shall use all of the relevant information obtained in the design process, the component tests and the field tests to complete the design of the proposed turbine. This systems-integration effort will require the development of drawings and specifications, analysis of structural loads and responses, and the analysis of performance and costs. At the conclusion of this task, the Subcontractor shall have produced all of the detailed drawings and specifications necessary to assemble an operable turbine.

All of the wind turbine components and subsystems will not be in the same stage of development at a particular time. To ensure the efficient and timely performance of the subcontract, it will be necessary to complete the design of some components and initiate the procurement of long-lead-time items before the design of others has been completed.

In the *Fabrication* and *POC Turbine Field Tests* subtasks, the Subcontractor shall proceed with the fabrication and testing of a POC turbine, the purpose of which is to demonstrate that the proposed NGT is likely to achieve the project objectives. The POC turbine need not be identical in size to the NGT production prototype that will be demonstrated later in the project, but it is important that the POC turbine incorporate the technology, innovations and design features that distinguish the NGT from other turbines of proven technology. Field tests of the POC turbine shall be conducted in order to verify its operation, performance, loads and structural response, to validate the Subcontractor's analytical methods and predictive codes, and to obtain data that can be extrapolated to subsequent prototypes.

Using all of the information obtained in the POC field tests, and only to the extent that is required, the Subcontractor shall repeat the design process described above and proceed with the fabrication and testing of an *Engineering and Manufacturing Development Turbine*. The EMD turbine shall be virtually identical in configuration and size to the NGT production prototype that will be demonstrated later in the project. It shall be used to demonstrate structural integrity and dynamic stability, to verify power performance and acoustic signature, and to develop and refine assembly procedures, installation procedures, safe operating procedures, operations and maintenance (O&M) procedures and control strategies. The EMD turbine shall also be used as a vehicle to refine analytical methods and predictive codes, to develop and test component improvements, to develop manufacturing methods and to generally improve the cost-effectiveness of the design.

Using all of the information obtained in the EMD field tests, and only to the extent that is required, the Subcontractor shall repeat the design process described above and proceed with the fabrication and testing of the *Next Generation Turbine (NGT) Production Prototype.* The NGT is intended to be the definitive product resulting from the Next Generation Turbine Development Project. The Subcontractor shall conduct comprehensive field tests of the turbine, including the demonstration of certain safety, performance and reliability criteria. After the field tests are completed, the Subcontractor shall prepare a *Final Report* and conduct a *Final Project Review*.

There are several occasions during the project when the Subcontractor shall conduct formal review meetings for the benefit of the project participants, including the NREL Technical Review Team. There are also three "go/no-go" decision points at which NREL, after consulting with the Subcontractor, will decide whether or not to proceed with the NGT development. These decisions, which will be based upon technical accomplishments and programmatic issues, coincide with critical project reviews to be conducted by NREL at the completion of the Final Design Review Meetings for the POC turbine, the EMD turbine and the NGT production prototype. If a decision is made by NREL not to proceed with the NGT development, the Subcontractor shall continue to work only on the final reporting for the project. NREL's close interaction with the Subcontractor, including both formal and informal review meetings, is expected to serve effectively in avoiding major problems that might otherwise lead to a "no-go" decision on the part of NREL.

WORK TASKS

The Subcontractor shall perform the work, conduct the meetings and deliver the work products described herein. In addition to the work described, specific Environmental Safety and Health and Quality Assurance concerns shall be addressed by the Subcontractor while planning and performing each work task so as to ensure that systematic methods will be used to evaluate ES&H and QA issues throughout the course of the project.

Task 1.0 Project Planning and Management

1.1 Project Management

The Subcontractor shall assign a competent Project Manager, preferably with proven wind-energy experience, to act as the primary interface with NREL and to oversee all aspects of the subcontract. He or she shall comply with the reporting requirements of the subcontract, keep NREL's Project Manager apprised of project status and coordinate the participation of NREL's Project Manager in important project activities. The Subcontractor's Project Manager shall be responsible for the ongoing maintenance of the Project Work Plan, including periodic reviews and updates.

1.2 Engineering and Manufacturing Liaison

The Subcontractor shall coordinate the activities of its design engineers and its manufacturing organization in order to successfully transition from the design, fabrication and testing of prototypes to the production of cost-effective commercial wind turbines. It shall provide engineering liaison between the engineering and manufacturing organizations to ensure efficient problem resolution, and to provide feedback from the manufacturing organization to the engineering team regarding recommended design changes.

Design-engineering and manufacturing-engineering activities shall be pursued in parallel throughout the project, not just with regard to commercialization of the NGT, but also with regard to fabrication of the POC turbine, the EMD turbine and the NGT production prototype. The Subcontractor shall conduct critical reviews of manufacturing decisions and it shall institute appropriate quality-assurance safeguards against manufacturing errors as well as design errors. It shall consult with NREL before a commitment is made to manufacturing materials, methods, specifications or tooling.

1.3 Certification Plan *Deliverable #1; Meeting #1*

The Subcontractor shall develop and implement a Certification Plan (Deliverable #1) to obtain design approval and type certification by a recognized international certification agency. The plan shall include the following elements, as a minimum.

- selection of the certification agency,
- involvement of the certification agency early in the project to facilitate the planning of design, documentation and test activities,
- periodic meetings between the Subcontractor, NREL and the certification agency to discuss the certification process, planning and requirement
- design of the NGT in accordance with IEC Standard[1] 1400-1,
- approval by NREL of the certification design requirements,
- development of a completely detailed specification of the NGT, with particular attention to the safety and control concept,

[1] *Wind Turbine Generator Systems - Part 1: Safety Requirements*, International Electrotechnical Commission (IEC), Technical Committee (TC) No. 88, Standard 1400-1, Draft Second Edition, November 1996.

- specification of the design loads, including,
  - identification of design load cases,
  - documentation of calculation methods, and
  - calculation of design loads and structural dynamic characteristics of the turbine,
- calculations and documentation of results that demonstrate the structural integrity of major components and subsystems,
- testing of components and subsystems as required by the certification agency, including,
  - procedures for calibration of instruments and data acquisition systems,
  - testing of the safety and control system, and
  - testing of the complete wind turbine for power performance, acoustic signature and structural loads, and
- documentation of the process for manufacturing, assembling, inspecting, transporting, installing and commissioning the turbine, including the overall quality management system.

The Certification Plan shall be integrated into the Project Work Plan such that NREL's subcontract requirements and the Subcontractor's certification efforts blend together efficiently. Where possible, NREL subcontract deliverables shall be coordinated with certification documents and NREL approval sought for acceptance of certification documents as subcontract deliverables. Similarly, NREL subcontract meetings shall be coordinated with certification meetings when appropriate. The Subcontractor shall develop a "document tree" to assist in planning the required project documentation and to show the relationship between NREL and certification reporting requirements.

After it is reviewed by the Subcontractor and key members of its development team, a draft Certification Plan shall be submitted to NREL no later than sixty days after subcontract award. The Subcontractor then shall conduct a certification planning meeting (Meeting #1) at its facilities within ninety days of the subcontract award date. At this meeting, the Subcontractor shall convene the key members of its team, the NREL Technical Review Team and representatives of the selected certification agency. The purpose of the meeting is to review, and revise as necessary, the Certification Plan for the NGT.

1.4 Project Work Plan *Deliverable #2*

The Subcontractor shall develop a Project Work Plan (Deliverable #2) that includes all of the details important to the subcontract effort and refines and expands upon the Prototype Development Plan submitted in its Stage-1 Concept Definition Study. The Project Work Plan, which is intended to guide the design, fabrication and testing of the POC, EMD and NGT turbines, shall describe the project work tasks, meetings, deliverables, organizational structure, labor plan, cost plan and time schedule for performing the subcontract. As a minimum, all of the activities identified in this Statement of Work shall be addressed in the Project Work Plan. Major work tasks shall be divided into subtasks of limited scope, each of which shall be described in sufficient detail to allow the project participants, including the NREL Technical Review Team, to understand and evaluate the proposed activities. For each task and subtask, the following information shall be provided.

- task number and name,
- work description, including objectives and expected results,
- a description of meetings or deliverables associated with the task,
- methods of testing and analyses, including iterative design procedures,
- special materials and facilities required, if any,
- anticipated analysis and test support requested of NREL, such as design reviews, design analysis, blade and full-system modal testing, blade structural testing and loans of equipment,
- required staffing, including consultants and lower-tier subcontractors, and
- milestones by which percent-complete will be assessed (minor tasks may use "completion" as the sole milestone; complex tasks of significant duration or expense may use either an estimated percent complete, or multiple milestones having associated percents-complete).

Besides the narrative descriptions of the work tasks, the Plan shall include the following information.

- a project organizational chart showing the relationship of employees, consultants and lower tier subcontractors under the Subcontractor's Project Manager or Principal Investigator,
- a project labor plan which tabulates labor hours by subtask and labor type for both employees and consultants, and which identifies the relevant skills, experience and responsibilities of lower-tier subcontractors and consultants,
- a statement-of-work and list of deliverables for each of the major activities involving lower-tier subcontractors and consultants,
- a tabulation of projected costs by subtask and cost category,
- a project cost plan, using the categories noted in Table 2 of Attachment D, showing the costs projected for each month of the subcontract and the cumulative costs by month,
- a network diagram showing the interrelationships of the proposed activities in a time-phased arrangement derived from a "critical path analysis",
- a project schedule Gantt-chart indicating the start date and duration of each activity and the entire project, with milestones, meetings and deliverables depicted on the schedule,
- a description of Environmental Safety and Health procedures in sufficient detail to ensure that the project will be performed with the highest regard for human health and safety, preservation of the environment and compliance with applicable laws, and
- a description of Quality Assurance procedures in sufficient detail to ensure that all work tasks are performed properly to achieve results that meet pre-determined quality levels.

In addition to the milestones, meetings and deliverables that are discussed in the Plan and indicated on the schedule, the Subcontractor shall identify those events that are critical to the timely and cost-effective completion of the project. Examples of these critical events are long-lead-time purchases, commitments to lower-tier subcontractors, critical project reviews and other activities requiring NREL consultation. If a commitment must be made in advance of a planned formal review meeting, the Subcontractor shall include in the Plan an informal review meeting to discuss the critical event with NREL. The Plan shall also reflect the likelihood that occasional informal review meetings will be necessary in addition to formal design reviews, test readiness reviews and other project milestones. In connection with periodic reports and reviews, the Subcontractor may be required to update the Project Work Plan. Therefore, provisions shall be made in the project labor plan, schedule and budget to accommodate ongoing maintenance of the Plan. As a minimum, the Plan shall be reviewed and updated in preparation for each annual DOE/NREL Subcontractor Review Meeting.

After it is reviewed by the Subcontractor and key members of its development team, a draft Project Work Plan shall be submitted to NREL no later than sixty days after the subcontract award date.

1.5 Kickoff Meeting *Meeting #2*

The Subcontractor shall conduct a kickoff meeting (Meeting #2) at its facilities within ninety days of the subcontract award date. At this meeting, the Subcontractor shall convene its key team members and the NREL Technical Review Team. In addition to the draft Project Work Plan, the Subcontractor shall discuss all aspects of the subcontract effort that have preceded the Kickoff Meeting. After the draft Project Work Plan has been delivered and the Kickoff Meeting has been conducted, the Subcontractor shall revise the Plan in consultation with NREL. This revised Project Work Plan, as well as any subsequent revisions of the Plan, must be approved by NREL.

Task 2.0 Conceptual Design

In Stage 1 of the NGTD Project, the Subcontractor developed its concept for a utility-grade wind turbine capable of meeting the project goals and objectives. Conceptual development work was continued under optional design studies that culminated in the delivery of a Design Review Package and participation in a Design Review Meeting. However, conceptual design does not necessarily terminate with the achievement of these project milestones. It may be necessary to continue the process in order to arrive at a point of departure for subsequent design efforts. In this task, the Subcontractor shall continue the conceptual design process as described below.

2.1 Trade-Off Studies

In consultation with the NREL technical staff, the Subcontractor shall continue to conduct trade-off studies of various design and manufacturing alternatives with the objective of refining its design concept. The objectives of this effort are to develop an understanding of the influential design parameters, to determine the effect of design choices on cost and performance, and to provide guidance in defining a refined configuration. Independent configuration variables, such as rotor geometry, rotational speed, tower height and overspeed control, shall be systematically investigated in order to determine their effect on COE and other figures-of-merit. Issues to be addressed in trade-off studies shall include, but not be limited to, the following topics.

- rotor diameter, tip speed and rated power,
- tower height and type (lattice, free-standing tubular, guyed tubular, etc.)
- design wind regime (IEC Class I, Class II, etc.),
- wind speed at which rated power occurs,
- cut-out wind speed,
- full-span pitch versus trailing-edge devices,
- pitch-to-feather versus pitch-to-stall
- blade manufacturing options,
- low-speed direct-drive generator versus geared drivetrain,
- variable-speed versus two-speed operation,
- generation at 600 Volts or higher versus 480 Volts,
- hydraulic versus electro-mechanical and servo-pneumatic actuators, and
- alternative rotor hub geometries.

In projects of large scope, it is difficult to identify all of the issues that may eventually be addressed in trade-off studies. Therefore, the Subcontractor shall conduct trade-off studies as necessary throughout the project in order to investigate key issues that may have a significant impact on the project goals and objectives.

2.2 Performance and Cost Analyses

By conducting appropriate analyses and performing the necessary calculations, the Subcontractor shall estimate the turbine performance at the COE Reference Sites designated in Attachment C. Turbine performance shall be represented by curves of electrical power as a function of wind speed for the configurations being considered. The Subcontractor shall develop estimates of component capital cost, component replacement cost and O&M cost; economic figures-of-merit shall be estimated in accordance with the methodology described in Attachment B.

2.3 Baseline Turbine Description *Deliverable #3*

In conclusion of the Conceptual Design task the Subcontractor shall identify a "baseline" turbine that will be used as a point of departure for subsequent studies. To accomplish this purpose, the Subcontractor shall provide NREL with a Baseline Turbine Description. The following information shall be included, as a minimum.

- photographs, drawings, paintings or other visual depictions of the baseline turbine showing its overall appearance and the details of its components and subsystems,
- a Configuration Description, using the format provided in Attachment A, and
- COE estimates, including supporting data, in accordance with Attachment B.

Task 3.0 Proof of Concept (POC) Turbine

In this task, the Subcontractor shall fabricate and test a Proof of Concept turbine, the purpose of which is to demonstrate that the proposed NGT is likely to achieve the project objective. The POC turbine need not be identical in size to the NGT production prototype that will be demonstrated later in the project, but it is important that the POC turbine incorporate the technology, innovations, features, components and subsystems that distinguish the NGT from other turbines of proven technology. Field tests of the POC turbine shall be conducted to verify its operation, performance, loads and structural response, validate the Subcontractor's analytical methods and predictive codes, and obtain data that can be extrapolated to subsequent prototypes. Therefore, the POC turbine is an engineering tool to be used in support of the NGT development.

3.1 Preliminary Design

The Subcontractor shall evaluate the baseline turbine, including components, subsystems and innovations, to assure that all relevant experience and information have been considered. It shall then integrate the selected components, subsystems and innovations into a preliminary design of the proposed POC turbine. This design integration will require interactions between several concurrent activities, including development of design drawings and specifications, analysis of structural loads and responses, and analysis of performance and costs. At the conclusion of this task, the Subcontractor shall describe in detail the configuration that it proposes to fabricate and test.

3.1.1 Designs, Drawings, Specifications

The Subcontractor shall develop designs, drawings and specifications as needed to define the POC turbine. Drawings and specifications shall be of sufficient detail to evaluate manufacturing alternatives and to support preliminary performance, structural and cost analyses. Documentation shall also include definition of the parameters listed in Attachment C for the Design Site.

3.1.2 Performance, Cost and Structural Analyses

The objectives of this subtask are to verify that the POC turbine meets general design criteria, to develop performance estimates, and to complete a preliminary structural analysis. In consultation with NREL, the Subcontractor shall choose established methods whose sophistication and complexity are appropriate for these preliminary design studies.

Using appropriate computational models, the Subcontractor shall refine its performance estimates for the POC turbine at the COE Reference Sites designated in Attachment C. Turbine performance shall be represented by curves of electrical power versus wind speed for the configurations considered.

Using appropriate computational models, the Subcontractor shall perform a preliminary structural analysis of the POC turbine at the Design Site specified in Attachment C. Calculations shall be performed according to IEC Standard 1400-1.

- Structural loads - The Subcontractor shall determine the design loads for the POC turbine using operational load cases as defined in IEC Standard 1400-1.

- Stress and fatigue analysis - The Subcontractor shall conduct a preliminary stress analysis of critical components and a preliminary fatigue analysis of the POC turbine rotor.

- Dynamic modeling - The Subcontractor shall develop dynamic models for critical components of the POC turbine, and conduct a preliminary system-dynamic analysis using approximations of the system geometry, component masses and stiffnesses.

- Failure Mode, Effect and Criticality (FMECA) analysis - The Subcontractor shall conduct a preliminary FMECA analysis to determine which components, and connections between components, are most critical in determining overall system reliability.

3.1.3 Preliminary Design Review *Deliverable #4; Meeting #3*

The Subcontractor shall conduct a review meeting (Meeting #3) at its facilities to discuss the preliminary design of its POC turbine. The meeting shall be attended by key members of the Subcontractor's design team and the NREL Technical Review Team. The Subcontractor or key members of its team shall present information that addresses the following topics.

- updated project status, including changes since last review,
- updated project schedule showing key milestones and deliverables,
- updated project cost summary,
- design philosophy and approach, including:
  - rationale for major design features,
  - techniques and sequence of analysis,
  - load cases considered, and
  - a description of control philosophy,
- engineering design, including:
  - trade-off-study results,
  - performance analysis methods and results,
  - component design loads,
  - rotor design information,
  - structural analysis methods and results,
  - identification of critical risks, and
  - descriptive drawings of major components and subsystems,
- updated Configuration Description, using the format provided in Attachment A,
- preliminary COE results and other figures of merit, if applicable,
- long-lead-time purchasing requirements, and
- anticipated tests of critical components.

To allow sufficient preparation time, multiple copies of a Preliminary Design Review Package (Deliverable #4) summarizing all of this material shall be provided to NREL at least three weeks in advance of the meeting.

3.2 Detailed Design (Component Development)

The Subcontractor shall design, fabricate, test and evaluate components and subsystems that are candidates for use on the proposed POC turbine. As part of this process, the Subcontractor shall demonstrate that the selected components and subsystems meet the specified design criteria. Because new information will be obtained as a result of the component development process, it shall be necessary to refine the performance estimates that were made previously. Furthermore, the Subcontractor shall endeavor to verify its predictive analytical methods and computer models using data obtained from laboratory and field tests of the components and subsystems that are investigated.

3.2.1 Component Design

The Subcontractor shall complete the design of the components and subsystems it is considering for use on the POC turbine. Stresses and deflections of critical load-bearing components shall be analyzed using finite element methods, and fatigue life calculations shall be performed for dynamically-loaded components. The probability of the components meeting their desired lifetimes with uncertain inputs shall be determined using a method such as the Failure and Reliability of Wind Turbine Components (FAROW)[2] analysis developed by Sandia.

Documentation of this effort shall include sketches, drawings, specifications, loads, calculated maximum and allowable stresses on the components and subsystems affected. By conducting appropriate analyses and performing necessary calculations, the Subcontractor shall estimate the effect that various alternatives would have on turbine performance, component capital cost, component replacement cost and O&M cost.

3.2.2 Component Test Plans *Deliverable #5*

The Subcontractor shall prepare Component Test Plans (Deliverable #5) to guide the testing of the components and subsystems it is considering for use on the POC turbine. In consultation with NREL, the Subcontractor shall identify the components and subsystems to be tested and the criteria by which they will be evaluated. The Component Test Plans shall indicate the minimum performance qualifications that must be met for each component, and the tests shall be designed to evaluate the performance of each component compared to its qualification criteria. The Component Test Plans shall describe each of the tests to be performed, including the following information, as a minimum:

- a description of the component or subsystem to be tested,
- the rationale for why the tests are required,
- predicted performance based on calculations or other analyses,
- the test objectives and technical approach,
- the test matrix showing the number of test conditions and replicated runs,
- the test schedule, budget and labor requirements,
- a description of the facilities, equipment and instrumentation required to conduct the tests,
- a description of test procedures, including parameters to be controlled and how they will be controlled; parameters to be measured and instrumentation to measure them; calibration procedures to be used; recommended re-calibration interval; and maintenance of a test log,
- a description of the data analysis procedures,
- a description of quality-assurance procedures,
- definition of the criteria that must be met for acceptance of the tested components,
- the Safe Operating Procedures (SOPs) necessary to protect employees, visitors and the environment from harm during all phases of testing, and
- contingency measures to be considered if the test objectives are not met.

[2] Veers, Paul S., et al. *Users Manual for FAROW: Failure and Reliability of Wind Turbine Components*, SAND94-2460, Sandia National Laboratories, Albuquerque, November 1994.

3.2.3 Component Acquisition

The Subcontractor shall fabricate, purchase or otherwise acquire the components and subsystems to be tested. Sufficient quantities shall be obtained to assure successful completion of the planned tests. The components shall be acquired in a fashion as closely resembling commercial procurement practices as is reasonable under the circumstances.

3.2.4 Component Testing

In accordance with the Component Test Plans developed in Subtask 3.2.2, the Subcontractor shall complete a qualification test program to ensure the suitability of the components and subsystems it is considering for use on the POC turbine. Test results shall be analyzed to determine if any changes are required in the component designs prior to incorporation in the POC turbine. If necessary, the Subcontractor shall identify follow-on measures it plans to take to ensure the suitability of the components. Documentation of the component and subsystem tests shall include the following information, as a minimum.

- the tests results,
- a description of any unusual occurrences during the tests, and
- additional analysis or tests that are anticipated.

3.2.5 Analysis of Test Results

The Subcontractor shall thoroughly analyze the component and subsystem test results and compare them to analytical predictions. If test results differ significantly from predictions, the Subcontractor shall evaluate why those differences exist. Consideration shall be given to potential problems with the testing process, the analytical methods, the input data to those methods, and conformity between the analytical models and tested components. If the predicted responses do not provide adequate safety factors or acceptable fatigue life, the Subcontractor shall propose appropriate remedial actions, such as derating components, decreasing lifetimes or redesigning critical components. If necessary, the subcontractor shall re-evaluate performance, cost and structural response information before making a final selection of the components and subsystems for use on the POC turbine.

3.3 Final Design (Systems Integration)

In this subtask, the Subcontractor shall use all of the information obtained in the design process, the component tests, and field tests of relevant turbines, to complete the design of the proposed POC turbine. This systems-integration effort will require interactions between several concurrent activities, including development of design drawings and specifications, analysis of structural loads and responses, and the analysis of performance and costs. At the conclusion of this task, the Subcontractor shall have developed the detailed drawings and specifications necessary for all of the components to be assembled into an operable turbine and for the project to advance to the field-testing stage.

3.3.1 Designs, Drawings, Specifications

The Subcontractor shall modify existing drawings and specifications and develop new drawings and specifications as needed to fully define the proposed POC turbine. These drawings and specifications shall be of sufficient detail that a comprehensive analysis can be conducted of performance, cost, loads and structural response.

3.3.2 Refinement of Performance, Cost and Structural Analyses

The component and subsystem design, test and analysis process may provide data that affect the performance and cost estimates. Therefore, the Subcontractor shall refine its performance estimates for the POC turbine at the COE Reference Sites designated in Attachment C. Turbine performance shall be represented by curves of electrical power as a function of wind speed for the configurations being considered.

The Subcontractor shall refine its estimated structural loads for the POC turbine at the Design Site specified in Attachment C. Calculations shall be performed according to IEC Standard 1400-1. For each of the following topics, the methods used and the depth of analysis shall be appropriate for the final systems integration effort.

- Structural loads - The Subcontractor shall refine the design loads for the POC turbine using operational load cases as defined in IEC Standard 1400-1.

- Stress analysis - The Subcontractor shall refine the stress analysis of the POC turbine and expand it to include all components of importance. Finite-element models shall be used to determine the stresses in all critical components and those of complex geometry.

- Fatigue analysis - The Subcontractor shall perform fatigue analyses on critical components of the POC turbine, including the tower, yaw system, chassis, gearbox, low-speed shaft, hub and blades. Results shall be used to estimate the useful life of these critical components.

- Dynamic modeling - The Subcontractor shall refine the dynamic model for critical components of the POC turbine that was developed in Subtask 3.1.2 and shall develop other models, as appropriate, to corroborate its analytical predictions.

3.3.3 System Dynamic Analysis

In previous subtasks, the structural dynamic analyses may have been limited to major components and subsystems. In this subtask an analysis of the fully-integrated wind turbine system shall be required. In addition, the Subcontractor shall develop appropriate analytical models and use them to estimate drivetrain dynamic loads resulting from sudden events. A transient braking-analysis shall also be conducted to estimate rotor stopping-time and brake-system energy absorption.

In consultation with NREL, the Subcontractor shall select and use methods whose sophistication and complexity are appropriate to this stage of the project, and which have been validated in previous studies by comparing predictions to field-test data. As the Prototype Development Project progresses, the Subcontractor shall endeavor to validate its models and computer codes by comparing predictions to field-test results.

3.3.4 Failure Mode, Effect and Criticality Analysis

The Subcontractor shall conduct a Failure Mode, Effect and Criticality Analysis (FMECA)[3] of the POC turbine, and apply systematic procedures for identifying the modes of failure and evaluating their consequences. The analysis shall consider each major part of the turbine, how it might fail and what the effects of this failure could be. The objectives of the FMECA are:

- to assist in selecting, early in the development process, design alternatives with high reliability and high safety potential,

[3] L. Rademakers and J. Carter, *Reliability Analysis of the AOC 15/50 Wind Turbine Generator*, ECN-C-94-057, Netherlands Energy Research Foundation ECN, November 1994.

- to identify potential failures and the magnitude of their effects,
- to ensure that all conceivable failure modes and their effects on the operational success of the turbine have been considered,
- to provide a basis for quantitative reliability and availability analyses,
- to collect data for a cost-benefit analysis,
- to provide historical documentation for future references, and
- to facilitate the analysis of field failures and the consideration of design changes.

In consultation with NREL, the Subcontractor shall choose established FMECA methods, and if necessary, it shall obtain the services of qualified consultants or lower-tier subcontractors that are experienced in the application of FMECA to wind turbine development.

3.3.5 Field Test Plan *Deliverable #6*

The Subcontractor shall develop a written plan for verifying, through full-scale atmospheric tests, the operation, performance, loads and structural response of the POC turbine. This plan shall support the validation of the Subcontractor's analytical methods and predictive codes, and produce data that can be extrapolated to subsequent prototypes. Information to be gathered during the tests shall include the operational status of the wind turbine, atmospheric inflow conditions, power output versus wind speed, critical stresses and accelerations, and any other data necessary to characterize the performance of the POC turbine.

The Field Test Plan (Deliverable #6) shall include the following information, as a minimum.

- a description of the prototype turbine, including the improved components to be tested,
- a prediction of power output versus wind speed,
- a prediction of loads for the rotor, drive train and tower,
- a prediction of system-dynamic response,
- a prediction of equilibrium tip speed ratio (free-wheeling rotor) with aerodynamic brakes deployed,
- a prediction of stopping time versus rotor power for the mechanical brake,
- the test objectives and technical approach,
- a prioritized list of data to be obtained and that which can be eliminated, if necessary,
- the test matrix showing the number of test conditions and replicated runs,
- the test schedule, budget and labor requirements,
- a description of the facilities, equipment and instrumentation required to conduct the tests,
- a description of test procedures, including parameters to be controlled and how they will be controlled; parameters to be measured and instrumentation to measure them; calibration procedures to be used; recommended re-calibration interval; maintenance of a test log,
- a description of the data analysis procedures,
- a description of quality-assurance procedures,
- a description of the potential hazards, and the measures to be taken to minimize the probability and consequences of their occurrence,
- the Safe Operating Procedures (SOPs) necessary to protect employees, visitors and the environment from harm during all phases of testing, and
- contingency measures to be considered if the test objectives are not met.

The Subcontractor shall submit a draft of the Field Test Plan to NREL, and the NREL Project Manager will provide comments to the Subcontractor within three weeks of the submission of the draft. The Subcontractor shall respond to NREL's comments, either by modifying the test plan as recommended, or by providing the Project Manager with written justification why the recommended revisions where not incorporated. The Subcontractor shall then submit its revised Field Test Plan.

3.3.6 Final Design Review *Deliverable #7; Meeting #4; Critical Project Review #1*

The Subcontractor shall conduct a Final Design Review Meeting (Meeting #4) to discuss its progress since the last review. The objectives of the meeting are to freeze the design of the POC turbine and to obtain NREL's concurrence that the Final Design task is complete, all relevant technical issues have been explored, the results of component tests have been used to reach appropriate conclusions, and the project is ready to advance to the field-testing stage. The meeting shall be held at the Subcontractor's facility and attended by key members of its design team and the NREL Technical Review Team. The Subcontractor or key members of its team shall present information that addresses the following topics.

- updated project status, including changes since the last review,
- updated project schedule showing key milestones and deliverables,
- updated project cost summary,
- recent performance history of relevant operating turbines, if applicable,
- design philosophy and approach, including:
  - rationale for major design features,
  - techniques and sequence of analysis,
  - operational strategies considered, and
  - description of control philosophy.
- engineering design, including:
  - trade-off-study results,
  - performance analysis methods and results,
  - component design loads,
  - rotor design details,
  - structural analysis methods and results,
  - wind-tunnel and field-test results,
  - identification of critical risks, and
  - descriptive drawings/specifications for major components and subsystems.
- review of the Component Testing task,
- updated Configuration Description, using the format provided in Attachment A,
- preliminary COE results and other figures-of-merit, if applicable, and
- plans for completion of the project, including
  - additional analysis and design activities,
  - additional component testing,
  - fabrication and installation activities, and
  - field tests of the prototype turbine.

In order to allow sufficient preparation time, a Final Design Review Package (Deliverable #7) summarizing all of this material shall be provided to NREL at least three weeks in advance of the meeting. The Subcontractor shall have supporting documentation available at the meeting, and it shall provide paper copies of any presentation material it uses.

After the Final Design Review Package has been delivered and the Final Design Review Meeting has been conducted, NREL will evaluate the project (Critical Project Review #1) and decide whether or not to proceed with the NGT development. This decision will be based upon technical accomplishments and programmatic issues. If a decision is made to proceed, the Subcontractor shall advance to the next work task. If a decision is made not to proceed, the Subcontractor shall continue to work only on the final reporting as described in Tasks 7.0, 8.0 and 9.0. For this reason, the Subcontractor shall focus its effort since the Kickoff Meeting on the POC turbine. In general, performance of the subcontract beyond the POC turbine design work, and the attendant expenditure of funds, shall not proceed until NREL approval is received to do so after Critical Project Review #1. If the Subcontractor wishes to commit resources to work beyond Subtask 3.3 before Critical Project Review #1 is successfully completed, it must make a formal request to the NREL Project Manager and receive authorization before proceeding.

3.4 Fabrication

The Subcontractor shall procure the components, assemble the POC turbine, and deliver it to the designated test site for installation and testing. Decisions regarding fabrication of the turbine shall be made within the overall context of the engineering-manufacturing liaison activity described in Subtask 1.2. Appropriate quality-assurance safeguards against manufacturing errors shall be instituted. For those components requiring fabrication to the Subcontractor's unique specifications, appropriate inspections shall be made to assure that fabrication and subsequent assembly are in accordance with the Subcontractor's specifications. The Subcontractor shall arrange for delivery of all components to the test site in a timely manner, and for them to be stored, safeguarded and insured in accordance with generally-accepted commercial practices.

3.5 Site Selection

The Subcontractor shall identify a site that is suitable for testing the POC turbine and is agreeable to NREL. The Subcontractor shall be responsible for site characterization, evaluation, access, permitting and community liaison. It shall obtain wind data and other information necessary to understand the operating conditions at the site, and it shall arrange for all necessary engineering and site-preparation work. If the National Wind Technology Center is chosen as the test site, NREL will assist with these items.

3.6 Installation

The Subcontractor shall deliver, assemble and install the POC turbine at the test site and provide all necessary equipment and subcontractors to do so. Site activities shall be conducted in compliance with applicable laws, generally-accepted commercial practices and prudent ES&H procedures.

3.7 POC Turbine Field Tests
3.7.1 Test Preparation

Field tests of the POC turbine shall be conducted at a site selected in consultation with NREL. It shall be the Subcontractor's responsibility to verify that the site has been adequately prepared including access roads, control buildings, utility-interface equipment, foundations, instruments and the turbine's control system. The Subcontractor shall install, checkout and calibrate data acquisition equipment and the other elements of the instrumentation system in order to obtain the information specified in the Field Test Plan. The instrumentation system is expected to include the following.

- transducers for measuring:
  - wind turbine operational status,
  - wind speed and direction at hub height,
  - ambient temperature and pressure,
  - nacelle yaw angle,
  - rotor RPM and position (azimuth),
  - blade pitch angle or trailing-edge device deflection, if appropriate,
  - aerodynamic brake deployment angle, if appropriate,
  - low-speed shaft torque and bending moments,
  - blade root bending moments (in-plane, out-of-plane and torsional, if appropriate),
  - nacelle accelerations,
  - tower loads, and
  - generator power.
- analog-to-digital signal conversion units,
- connecting cables, telemetry units and/or slip-rings,
- computer hardware and software for pre-processing, monitoring and storing data, and
- transducer power sources and conditioners.

3.7.2 Checkout and Commissioning

The Subcontractor shall conduct appropriate checkout tests of the POC turbine in order to ensure that it operates as expected and is safe to commission. Checkout tests of the turbine will be complete when the Subcontractor has demonstrated that the turbine's control and safety systems operate according to specifications. Specific tests that must be successfully completed before commissioning are as follows.

- prevention of overspeed by deploying the primary brake system on a free-wheeling rotor at a wind speed of at least 15 m/s,
- stopping the turbine using only the secondary brake system at a wind speed of at least 15 m/s,
- stopping the turbine under a "loss of utility power" scenario, and
- other checkout tests identified in the Field Test Plan.

Any deficiencies that are noted during the checkout tests shall be rectified prior to the commissioning of the POC turbine.

3.7.3 Test Readiness Review *Meeting #5*

After successfully completing the checkout tests, the Subcontractor shall conduct a Test Readiness Review (Meeting #5) describing the installation of the turbine and the test equipment. The meeting shall be held at the Subcontractor's facilities and attended by key members of its team and the NREL Technical Review Team. The Subcontractor or key members of its team shall conduct a tour of the test site, including a safety briefing, and provide the information necessary to demonstrate that the prototype turbine is ready for testing and safe to operate. At NREL's sole discretion, a site visit by the NREL Project Manager may substitute for a formal Test Readiness Review meeting. At the successful conclusion of the Test Readiness Review meeting, and only with NREL concurrence, the Subcontractor shall commission the turbine and begin long-term testing.

3.7.4 Field Testing

In accordance with the Field Test Plan developed in Subtask 3.3.5, the Subcontractor shall conduct field-tests of the POC turbine for a period of time necessary to achieve the test objectives. The Subcontractor shall arrange for preventative and corrective maintenance to keep the turbine in good operating condition, and it shall systematically record information on maintenance occurring during the test period. Should any major failures occur during the test period, the Subcontractor shall notify NREL as soon as possible.

3.7.5 Analysis of Test Results

The Subcontractor shall thoroughly analyze the test results and compare them to analytical predictions. If test results differ significantly from predictions, the Subcontractor shall evaluate why those differences exist. Consideration shall be given to potential problems with the testing process, the analytical methods, the input data to those methods, and conformity between the analytical models and tested components. If the predicted responses do not provide adequate safety factors or acceptable fatigue life, the Subcontractor shall propose appropriate remedial actions, such as derating the turbine's wind-speed operating range, decreasing component lifetimes or redesigning critical components.

Task 4.0 Engineering and Manufacturing (EMD) Development Turbine

In this task, the Subcontractor shall repeat the design process described in Task 3.0, except as modified in the following subtasks, and proceed with the fabrication and testing of an engineering and manufacturing development turbine. The EMD turbine shall be virtually identical in configuration and size to the NGT production prototype that will be demonstrated later in the project. It shall be used to demonstrate structural integrity and dynamic stability, to verify power performance and acoustic signature, and to develop and refine assembly procedures, installation procedures, safe operating procedures, O&M procedures and control strategies. The EMD turbine shall also be used as a vehicle to refine analytical methods and predictive codes, to develop and test component improvements, to develop manufacturing methods, and to generally improve cost-effectiveness.

4.1 Preliminary Design *Deliverable #8; Meeting #6*

To the extent that is required, the Subcontractor shall repeat the preliminary design process described in Subtask 3.1. Some issues that were unimportant in the design of the POC turbine may be important in the design of the EMD turbine. In particular, the influence of airfoil selection, blade planform, rotational speed, nacelle design and tower shadow on noise shall be considered in the design process. In addition, the estimates of component capital cost, component replacement cost and O&M cost shall be refined, and economic figures-of-merit shall be estimated in accordance with the methodology described in Attachment B. Documentation provided to NREL by the Subcontractor shall include definition of the parameters listed in Attachment C for the Design site, which is representative of the market in which the NGT will be sold. At the conclusion of the process, the Subcontractor shall conduct a review meeting (Meeting #6) at its facilities to discuss the preliminary design of the EMD turbine. The meeting shall be attended by key members of the Subcontractor's design team and the NREL Technical Review Team. The Subcontractor or key members of its team shall present information that addresses the same topics listed in Subtask 3.3. In order to allow sufficient preparation time, multiple copies of a Preliminary Design Review Package (Deliverable #8) summarizing all of this material shall be provided to NREL at least three weeks in advance of the meeting.

4.2 Detailed Design (Component Development) *Deliverable #9*

To the extent that is required, the Subcontractor shall repeat the detailed design process described in Task 3.2. Design activities shall focus on determining the effect that component improvements will have on performance, component capital cost, component replacement cost and O&M cost. The Subcontractor shall prepare Component Test Plans (Deliverable #9) to guide the testing of the components and subsystems it is considering for use on the EMD turbine. In consultation with NREL, the Subcontractor shall identify the components to be tested and the criteria by which they will be evaluated. The Component Test Plans shall indicate the minimum performance qualifications that must be met for each component, and tests shall be designed to evaluate the performance of each component compared to its qualification criteria. The Component Test Plans shall describe the tests to be performed, including topics listed in Subtask 3.2.2. As a minimum, the following tests shall be included in the component development effort.

- gearbox stress, noise, wear, endurance and efficiency,
- power-electronic converter noise and efficiency,
- generator noise and efficiency,
- mainframe stress, deflections and endurance,
- blade material coupon tests,
- blade fatigue-strength tests,
- blade ultimate static-strength tests,
- blade and tower modal tests,
- simulation tests of control-system hardware and software, and
- endurance tests of aerodynamic control surfaces and actuators.

4.3 Final Design (Systems Integration) *Deliverables #10 and #11; Meeting #7 Critical Project Review #2*

To the extent that is required, the Subcontractor shall repeat the final design process described in Task 3.3. Estimates of component capital cost, component replacement cost and O&M cost shall be refined, and economic figures-of-merit shall be estimated in accordance with the methodology described in Attachment B. The Subcontractor also shall develop a written plan for verifying, through full-scale atmospheric tests, the operation, performance, loads and structural response of the EMD turbine. In particular, full-system modal tests shall be required by NREL in this subtask. The Field Test Plan (Deliverable #10) shall include all of the information listed in Subtask 3.3.5. Some issues that were unimportant in testing the POC turbine may be important in testing the EMD turbine. In particular, full-system modal tests, acoustics tests and power quality tests (wave form, total harmonic distortion, power factor, etc.) shall be conducted. The Subcontractor shall submit a draft of the Field Test Plan to NREL, and the NREL Project Manager will provide comments to the Subcontractor within three weeks of the submission of the draft. The Subcontractor shall respond to NREL's comments, either by modifying the test plan as recommended, or by providing the NREL Project Manager with written justification why the recommended revisions where not incorporated. The Subcontractor shall then submit its revised Field Test Plan.

At the conclusion of the final design process, the Subcontractor shall conduct a meeting (Meeting #7) to discuss its progress since the last review. The objectives are to stabilize the configuration and obtain NREL concurrence that the Final Design task is complete, all relevant technical issues have been explored, the results of component tests have been used to reach appropriate conclusions, and the project is ready to advance to the field-testing stage. The meeting shall be held at the Subcontractor's facility and attended by key members of its design team and the NREL Technical Review Team. The Subcontractor or key members of its team shall present information that addresses the same topics listed in Subtask 3.3.6. To allow sufficient preparation time, a Final Design Review Package (Deliverable #11) summarizing all of this material shall be provided to NREL at least three weeks in advance of the meeting. The Subcontractor shall have supporting documentation available at the meeting, and it shall provide paper copies of any presentation material it uses.

After the Final Design Review Package has been delivered and the Final Design Review Meeting has been conducted, NREL will evaluate the project (Critical Project Review #2) and decide whether or not to proceed with the NGT development. This decision will be based upon technical accomplishments and programmatic issues. If a decision is made to proceed, the Subcontractor shall advance to the next work task. If a decision is made not to proceed, the Subcontractor shall continue to work only on the final reporting as described in Tasks 7.0, 8.0 and 9.0. For this reason, the Subcontractor shall focus its effort since the last critical project review on the EMD turbine. In general, performance of the subcontract beyond the EMD turbine design work, and the attendant expenditure of funds, shall not proceed until NREL approval is received to do so after Critical Project Review #2. If the Subcontractor wishes to commit resources to work beyond Subtask 4.3 before Critical Project Review #2 is completed, it must make a formal request to the NREL Project Manager and receive authorization before proceeding.

4.4 Fabrication

The Subcontractor shall procure the components, assemble the EMD turbine, and deliver it to the designated test site for installation and testing. Decisions regarding fabrication of the turbine shall be made within the overall context of the engineering-manufacturing liaison activity described in Subtask 1.2. Appropriate quality-assurance safeguards against manufacturing errors shall be instituted. For those components requiring fabrication to the Subcontractor's unique specifications, appropriate inspections shall be made to assure that fabrication and subsequent assembly are in accordance with the Subcontractor's specifications. The Subcontractor shall arrange for delivery of all components to the test site in a timely manner, and for them to be stored, safeguarded and insured in accordance with generally-accepted commercial practices.

4.5 Site Selection

The Subcontractor shall identify a site that is suitable for testing the EMD turbine and is agreeable to NREL. The designated test site may be the same site at which the POC turbine was installed and tested, or it may be a different site that is agreeable to NREL. The Subcontractor shall be responsible for site characterization, evaluation, access, permitting and community liaison. It shall obtain wind data and other information necessary to understand the operating conditions at the site, and it shall arrange for all necessary engineering and site-preparation work. If the National Wind Technology Center is chosen as the test site, NREL will assist in providing these items.

4.6 Installation

The Subcontractor shall deliver, assemble and install the EMD turbine at the test site and provide all necessary equipment and subcontractors to do so. Site activities shall be conducted in compliance with applicable laws, generally-accepted commercial practices and prudent ES&H procedures.

4.7 EMD Turbine Field Tests *Meeting #8*

At a site selected in consultation with NREL, the Subcontractor shall conduct field tests of the EMD turbine in accordance with the Field Test Plan developed in Subtask 4.3 and the process described in Subtasks 3.7.1 through 3.7.5. As part of this process, the Subcontractor shall conduct a Test Readiness Review (Meeting #8) describing the installation of the turbine and the test equipment. The meeting shall be held at the Subcontractor's facilities and attended by key members of its team and the NREL Technical Review Team. The Subcontractor or key members of its team shall conduct a tour of the test site, including a safety briefing, and provide the information necessary to demonstrate that the EMD turbine is ready for testing and safe to operate. At NREL's sole discretion, a site visit by the NREL Project Manager may substitute for a formal Test Readiness Review meeting. At the successful conclusion of the Test Readiness Review meeting, and only with NREL concurrence, the Subcontractor shall commission the turbine and begin long-term testing.

Task 5.0 Next Generation Turbine (NGT) Production Prototype

In this task, the Subcontractor shall repeat the design process described in Task 3.0, except as modified in the following subtasks, and proceed with the fabrication and testing of the NGT Production Prototype. This turbine is intended to be the definitive product resulting from the Prototype Development Project. The Subcontractor shall conduct comprehensive field tests, including demonstration of certain safety, performance and reliability criteria. The design and test activity conducted on the NGT Production Prototype shall be directed at obtaining certification of the NGT by a recognized Certification Agency.

5.1 Preliminary Design *Deliverable #12; Meeting #9*

To the extent that is required, the Subcontractor shall repeat the preliminary design process described in Subtask 3.1 as modified to reflect the commercial objectives of the NGT and the requirements for its certification. In addition, the estimates of component capital cost, component replacement cost and O&M cost shall be refined, and economic figures-of-merit shall be estimated in accordance with the methodology described in Attachment B. At the conclusion of the process, the Subcontractor shall conduct a review meeting (Meeting #9) at its facilities to discuss the preliminary design of the NGT Production Prototype. The meeting shall be attended by key members of the Subcontractor's design team and the NREL Technical Review Team. The Subcontractor or key members of its team shall present information that addresses the same topics listed in Subtask 3.1.3. In order to allow sufficient preparation time, multiple copies of a Preliminary Design Review Package (Deliverable #12) summarizing all of this material shall be provided to NREL at least three weeks in advance of the meeting.

5.2 Detailed Design (Component Development) *Deliverable #13*

To the extent that is required, the Subcontractor shall repeat the detailed design process described in Task 3.2 as modified to reflect the commercial objectives of the NGT and the requirements for its certification. The Subcontractor shall prepare Component and Subsystem Test Plans (Deliverable #13) to guide the testing of the components it is considering for use on the NGT Prototype. In consultation with NREL, the Subcontractor shall identify the components to be tested and the criteria by which they will be evaluated. Ultimate-strength and fatigue-strength tests of the turbine blades shall be required by NREL in this subtask. The Component Test Plans shall indicate the minimum performance qualifications that must be met for each component, and the tests shall be designed to evaluate the performance of each component compared to its qualification criteria. The Component Test Plans shall describe each of the tests, including the topics listed in Subtask 3.2.2.

5.3 Final Design (Systems Integration) *Deliverables #14 and #15; Meeting #10 Critical Project Review #3*

To the extent required, the Subcontractor shall repeat the final design process which is described in Task 3.3 as modified to reflect the commercial objectives of the NGT and the requirements for its certification. In addition, the estimates of component capital cost, component replacement cost and O&M cost shall be refined, and economic figures-of-merit shall be estimated in accordance with the methodology described in Attachment B. The Subcontractor also shall develop a written plan for verifying, through full-scale atmospheric tests, the operation, performance, loads and structural response of the NGT Production Prototype. The Field Test Plan (Deliverable #14) shall include all of the information listed in Subtask 3.3.5. The Subcontractor shall submit a draft of the Field Test Plan to NREL, and the NREL Project Manager will provide comments to the Subcontractor within three weeks of the submission of the draft. The Subcontractor shall respond to NREL's comments, either by modifying the test plan as recommended, or by providing the Project Manager with written justification why the recommended revisions where not incorporated. The Subcontractor shall then submit its revised Field Test Plan.

At the conclusion of the final design process, the Subcontractor shall conduct a review meeting (Meeting #10) to discuss its progress. The objectives are to stabilize the configuration and obtain NREL concurrence that the Final Design task is complete, all relevant technical issues have been explored, the results of component tests have been used to reach appropriate conclusions, and the project is ready to advance to the field-testing stage. The meeting shall be held at the Subcontractor's facility and attended by key members of its design team and the NREL Technical Review Team. The Subcontractor or key members of its team shall present information that addresses the same topics listed in Subtask 3.3.6, and any other topics that may be relevant to the certification process. In order to allow sufficient preparation time, a Final Design Review Package (Deliverable #15) summarizing all of this material shall be provided to NREL at least three weeks in advance of the meeting. The Subcontractor shall have supporting documentation available at the meeting, and it shall provide paper copies of any presentation material it uses.

After the Final Design Review Package has been delivered and the Final Design Review Meeting has been conducted, NREL will evaluate the project (Critical Project Review #3) and decide whether or not to proceed with the NGT development. This decision will be based upon technical accomplishments and programmatic issues. If a decision is made to proceed, the Subcontractor shall advance to the next work task. If a decision is made not to proceed, the Subcontractor shall continue to work only on the final reporting as described in Tasks 7.0, 8.0 and 9.0. For this reason, the Subcontractor shall focus its effort since the last critical project review on the NGT Production Prototype. In general, performance of the subcontract beyond the NGT Production Prototype design work, and the attendant expenditure of funds, shall not proceed until NREL approval is received to do so after Critical Project Review #3. If the Subcontractor wishes to commit resources to work beyond Subtask 5.3 before Critical Project Review #3 is successfully completed, it must make a formal request to the NREL Project Manager and receive authorization before proceeding.

5.4 Fabrication

The Subcontractor shall procure the components, assemble the NGT Production Prototype, and deliver it to the designated test site for installation and testing. Decisions regarding fabrication of the turbine shall be made within the overall context of the engineering-manufacturing liaison activity described in Subtask 1.2. Appropriate quality-assurance safeguards against manufacturing errors shall be instituted. For those components requiring fabrication to the Subcontractor's unique specifications, appropriate inspections shall be made to assure that fabrication and subsequent assembly are in accordance with the Subcontractor's specifications. The Subcontractor shall arrange for delivery of all components to the test site in a timely manner, and for them to be stored, safeguarded and insured in accordance with generally-accepted commercial practices.

5.5 Site Selection

The Subcontractor shall identify a site that is suitable for testing the NGT Production Prototype and is agreeable to NREL. The designated test site may be the same site at which the POC or EMD turbine was installed and tested, or it may be a different site that is agreeable to NREL. However, NREL will not support the development of a third site. No more than two sites will be developed under this subcontract. Therefore, the Subcontractor should consider developing one site for testing both the EMD turbine and the NGT Production Prototype. Ideally, this site would be in close proximity to the Subcontractor's engineering facility and would be of long-term benefit to its turbine development efforts. The Subcontractor shall be responsible for site characterization, evaluation, access, permitting and community liaison. It shall obtain wind data and other information necessary to understand the operating conditions at the site, and it shall arrange for all necessary engineering and site-preparation work. If the National Wind Technology Center is chosen as the test site, NREL will assist in providing these items.

5.6 Installation

The Subcontractor shall deliver, assemble and install the EMD turbine at the test site and provide all necessary equipment and subcontractors to do so. Site activities shall be conducted in compliance with applicable laws, generally-accepted commercial practices and prudent ES&H procedures.

5.7 NGT Production Prototype Field Testing *Meeting #11*

At a site selected in consultation with NREL, the Subcontractor shall conduct field tests of the NGT Production Prototype in accordance with the Field Test Plan developed in Subtask 5.3 and the process described in Subtasks 3.7.1 through 3.7.5. As part of this process, the Subcontractor shall conduct a Test Readiness Review (Meeting #11) describing the installation of the turbine and the test equipment. The meeting shall be held at the Subcontractor's facilities and attended by key members of its team and the NREL Technical Review Team. The Subcontractor or key members of its team shall conduct a tour of the test site, including a safety briefing, and provide the information necessary to demonstrate that the NGT Production Prototype is ready for testing and safe to operate. At NREL's sole discretion, a site visit by the NREL Project Manager may substitute for a formal Test Readiness Review meeting. At the successful conclusion of the Test Readiness Review meeting, and only with NREL concurrence, the Subcontractor shall commission the turbine and begin long-term testing.

The Subcontractor shall use internationally recognized testing procedures[4,5,6,7,8,9,10] as guidelines for planning and conducting field tests. Alternative procedures may be acceptable to NREL, if they meet the desired standards for quality. In particular, field tests of power performance and acoustic emissions shall be conducted in accordance with the latest edition of the International Electrotechnical Commission (IEC) standards.[11,12]

Field tests shall extend through at least one wind season, and be continued until the turbine successfully completes the test matrix identified in the Field Test Plan. As a minimum, the subcontractor shall obtain sufficient data to:

- characterize the aerodynamic overspeed-protection system by obtaining at least one hour of consistent data at wind speeds of 5 m/s to 20 m/s with the turbine off-line, rotor free-wheeling, aerodynamic overspeed-protection system deployed,
- ensure characterization of structural and dynamic response including:
  - two hours of operation in each of five wind-speed ranges, including 0-5 m/s, 5-10 m/s, 10-15 m/s, 15-20 m/s and 20-25 m/s,
  - ten minutes with the rotor parked, in each of the five wind-speed ranges listed, at yaw angles of zero (±20), 90 (±20), and 180 (±20) degrees, if applicable,
  - eight normal start-ups under both low and high wind conditions,
  - eight normal shutdowns under both low and high wind conditions, and
  - one emergency stop with winds in excess of 25 m/s,
- ensure reliable operation in an unattended, automatic mode including:
  - 3,000 hours of operation of any single prototype turbine, and
  - 1,000,000 kWh of energy production from any single prototype turbine.

Field tests shall also demonstrate the turbine's capability to interface (via the controller's serial port) with a supervisory control and data acquisition (SCADA) system, including the following functions.

- monitoring turbine status, such as, ready/faulted, on-line/off-line, major fault conditions,
- monitoring of power production or consumption, and
- ability to shut down the turbine and return it to ready status.

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[4] Madsen, Peter H., et al. *Recommended Practices for Wind Turbine Testing: 3. Fatigue Loads.* Submitted to the Executive Committee of the International Energy Agency Programme for Research and Development on Wind Energy Conversion Systems. Paris, 1990.

[5] *Guidelines for Technical Specifications for Measurement Systems.* WEGA-II Large Wind Turbine Scientific Evaluation Project. ELASMPROJEKT A/S Report EP94/765, Sept. 1994.

[6] *Guidelines for Data Collection and Qualification.* WEGA-II Large Wind Turbine Scientific Evaluation Project. ELASMPROJEKT A/S Report EP94/777, February 1995.

[7] *Guidelines for Sensor and System Calibrations.* WEGA-II Large Wind Turbine Scientific Evaluation Project. ELASMPROJEKT A/S Report EP94/776, February 1995.

[8] *Guidelines for the Location of Sensors.* WEGA-II Large Wind Turbine Scientific Evaluation Project. ELASMPROJEKT A/S Report EP94/774, February 1995.

[9] *Guidelines for Coordinate System Definitions.* WEGA-II Large Wind Turbine Scientific Evaluation Project. ELASMPROJEKT A/S Report EP96/126a, February 1996.

[10] *European Wind Turbine Standards: Volume 6. Mechanical Load Measurements.* Seifert, Henry, et al. Joule II Programme, Contract No. JOU2-CT93-0387. EUREC-Agency, 1996.

[11] *Wind Turbine Generator Systems - Part 10: Acoustic Noise Measurement Techniques*, International Electrotechnical Commission (IEC), Technical Committee (TC) No. 88, Standard 1400-10, First Edition, June 15, 1994.

[12] *Wind Turbine Generator Systems - Part 12: Power Performance Measurement Techniques*, International Electrotechnical Commission (IEC), Technical Committee (TC) No. 88, Standard 1400-12, CDV Draft, February 8, 1994.

Should any hardware or software changes be made to the turbine during the test period, the Subcontractor shall begin the tests anew, unless it can demonstrate to NREL's satisfaction that the cumulative effect of any changes will not significantly alter the results of performance, braking, structural and dynamic response or reliability tests.

Task 6.0 Manufacturing, Maintenance and Commercialization Plans

Using all of the information obtained in the project, particularly in the engineering-manufacturing liaison, fabrication and testing activities, the Subcontractor shall develop a plan for manufacturing, assembling, inspecting, acceptance-testing and installing production quantities of the NGT. The plan shall focus on production requirements for the tower, nacelle, rotor, drive train and electrical/control systems, and it shall incorporate the Subcontractor's ES&H and QA procedures.

The Subcontractor shall develop an O&M plan reflecting deployment of the NGTs in a 50-MW wind powerplant. The plan shall define the Subcontractor's approach to wind turbine maintenance, and it shall include a proposed maintenance schedule.

The Subcontractor shall develop a commercialization plan that identifies its perceived markets and the methods by which the NGTs will be introduced.

Task 7.0 Draft Final Report *Deliverable #16*

Using appropriate engineering calculations, drawings, graphs and narrative descriptions, the Subcontractor shall prepare a Draft Final Report summarizing all work performed under the subcontract. The Draft Final Report shall be prepared in two volumes. Volume I shall provide an overview of the project and highlight the important technical work and results. Volume II shall describe all significant technical work performed during the project. Design analyses and engineering documentation shall be updated to reflect the as-built-and-tested components, and results of the field-test program shall be included. The final configuration of the NGT Production Prototype, including refinements that are anticipated in moving from the tested configuration to a commercial product, shall be described.

The specific topics to be covered in the Draft Final Report, and an outline of their presentation, shall be decided in consultation with the NREL Project Manager. Some of the information will be the same as that required by wind-turbine certification agencies. Therefore, documents produced by the Subcontractor to comply with certification requirements may also meet NREL's final reporting requirements. As a minimum, the following sections shall appear in the Draft Final Report.

Field Test Results

The Subcontractor shall document its NGT Production Prototype field tests by providing the following information, as a minimum.

- a description of the NGT Production Prototype, including the improved components that were tested and any changes that were made during the field tests,
- test objectives and technical approach,
- a description of the facilities, equipment and instrumentation used to conduct the tests,
- a description of test procedures, including parameters to be controlled and how they will be controlled; parameters to be measured and instrumentation to measure them; test matrix showing the number of test conditions and replicated runs; calibration procedures to be used,
- a description of the data analysis procedures,

- a comparison of predicted and measured power output versus wind speed,
- a comparison of predicted and measured loads for the critical load paths through the rotor, drive train and tower,
- a comparison of predicted and measured aerodynamic braking performance,
- a comparison of predicted and measured mechanical braking performance,
- a comparison of predicted and measured system-dynamic response,
- availability and reliability data, and
- a description of any unusual occurrences during the tests.

If the field-test results indicate that the turbine does not meet specifications, the Subcontractor shall identify the follow-on measures it will take to ensure that the project goal and objective are met.

Structural Design Data

The Subcontractor shall document its structural design effort by providing the following information, as a minimum.

- design load cases with references showing the origin and development of each load case,
- detailed structural analyses showing partial factors of safety,
- a plot of the spectral content of the critical loads,
- updated projection of the turbine's fatigue life, and
- updated failure modes and effects analysis.

NGT Production Prototype Description

The Subcontractor shall document the configuration of the NGT Production Prototype by providing the following information, presented in the same format used in subtask 2.3 for the Baseline Turbine Description.

- a photograph, drawing, painting or other visual depiction of the NGT Production Prototype showing its overall appearance, but not necessarily the details of its components and subsystems,
- a narrative description of the NGT Production Prototype, and the modifications that were made to the baseline turbine,
- a Configuration Description, using the format provided in Attachment A,
- COE estimates, including supporting data, in accordance with Attachment B,
- the test matrix showing wind conditions and turbine operating conditions that were actually tested, and the number of data sets that were actually obtained for each test,
- a comparison of predicted and measured power output versus wind speed,
- a comparison of predicted and measured loads for the rotor, drive train and tower,
- comparisons of predicted and measured braking performance (normal and emergency), and
- preliminary plans for component or subsystem improvements.

The Subcontractor shall also provide three-view, isometric, and/or assembly drawings of all major components and subsystems sufficient to completely describe the prototype turbine. Mechanical drawings, electrical schematics and control-logic diagrams of the electrical-control system shall also be provided.

Other Topics

The Draft Final Report shall also contain separate sections which address the following topics.

- design documentation submitted to certification agencies,
- manufacturing process,
- assembly procedures,
- acceptance procedures,
- installation procedures,
- quality assurance procedures, and
- operations and maintenance procedures.

Task 8.0 Final Project Review ***Meeting #12***

The Subcontractor shall conduct a Final Project Review meeting at NREL during which the contents of the Draft Final Report are presented. The objective of the meeting is to obtain NREL concurrence that field tests of the NGT Production Prototype are complete, that all relevant technical issues have been explored, that the results of field tests have been used to reach appropriate conclusions, and that documentation of the final configuration will lead toward customer and certification-agency acceptance. The Subcontractor or key members of its team shall present information that addresses the following topics.

- updated project status, including changes since the last review,
- updated project schedule showing key milestones and deliverables,
- updated project cost summary,
- recent performance history of operating turbines,
- review of the Draft Final Report, and
- plans for completion of the project, including
  - additional analysis and design activities,
  - additional component testing,
  - additional field testing, and
  - final reporting.

In order to allow sufficient preparation time, the Draft Final Report and any other pertinent material shall be provided to NREL at least three weeks in advance of the meeting. The Subcontractor shall have supporting documentation available at the meeting, and it shall provide paper copies of any presentation material it uses.

Task 9.0 Revised Final Report ***Deliverable #17***

NREL will provide the Subcontractor with written comments on the Draft Final Report within thirty days of its presentation at the Final Review meeting. The Subcontractor shall incorporate those comments into the report as appropriate and then submit a Revised Final Report.

Task 10.0 Scale Models ***Deliverable #18***

The Subcontractor shall fabricate and deliver to NREL two (2) scale models of the prototype turbine as represented in the final Configuration Description. The 1:40 scale models shall accurately depict the turbine's external physical features, and approximate their teeter motion, rotor rotation and yaw motion.